The Swarm at the Edge of the Cloud

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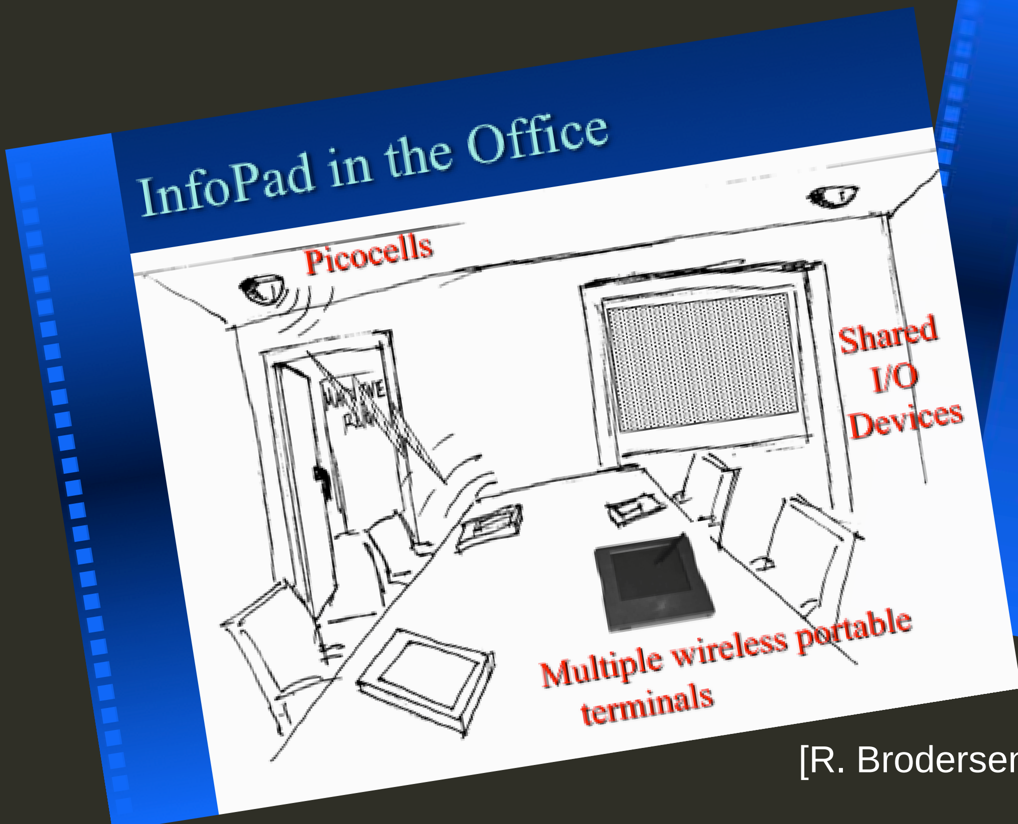
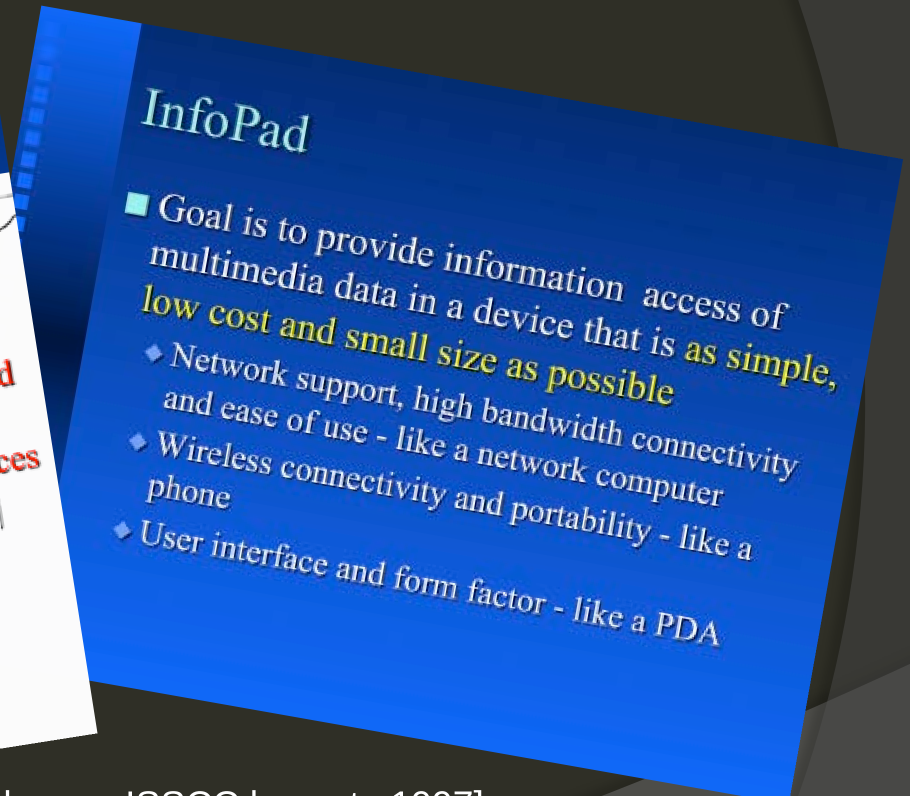
BEARS, February 17, 2011

Vision 2010

1990 Question: What Happens to Computers if Wireless Connectivity Becomes Ubiquitous?





[R. Brodersen, ISSCC keynote 1997]

The UCB Infopad Project (1992-1996)

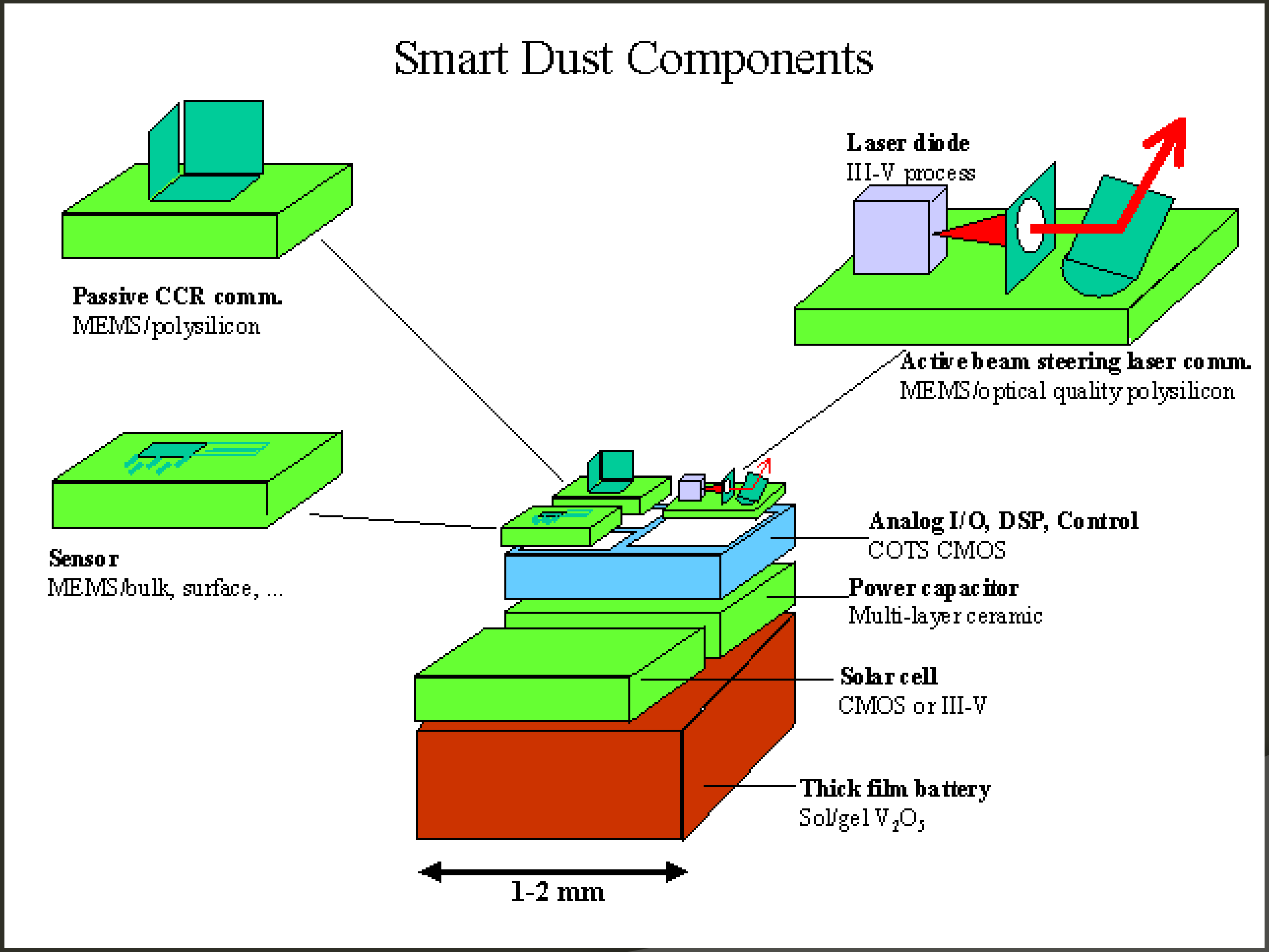
The Birth of the Wireless Tablet

Vision 2010:
The Mobile as Gateway to the Cloud

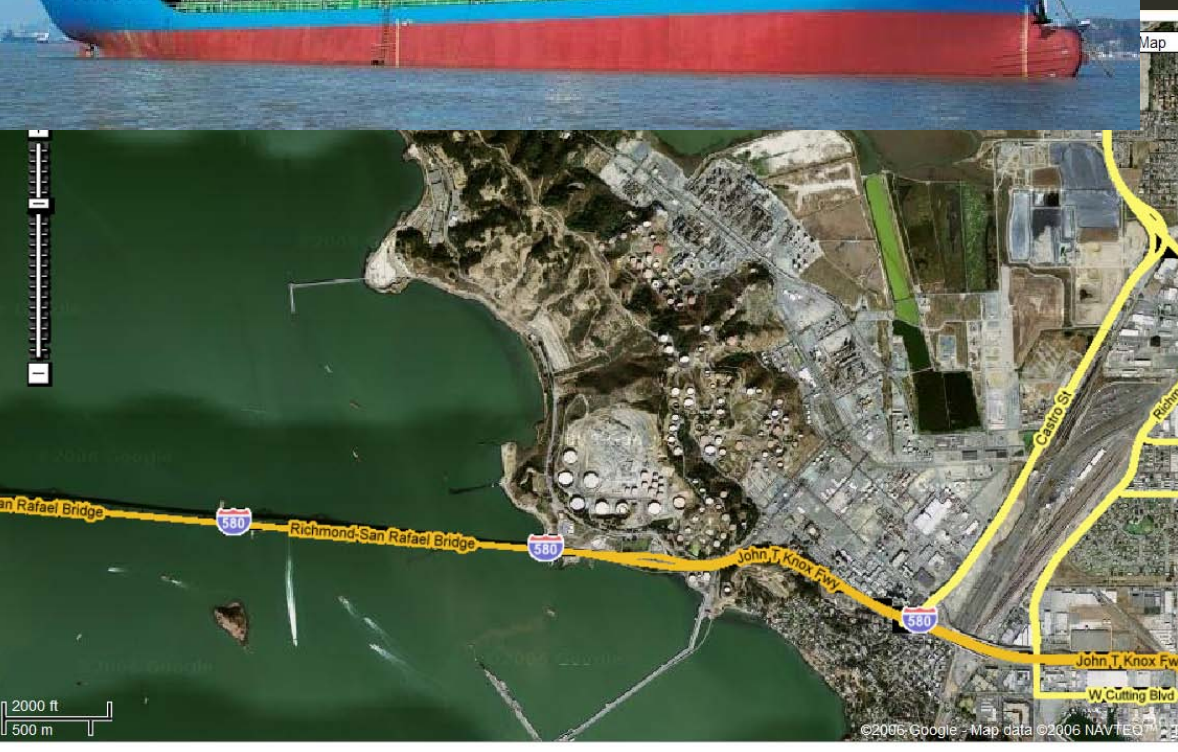
- Primary intent: interact with the Internet

Vision 2010

1997 Question: What happens if sensors become tiny and wireless?




2 INCH HF COMP SHOES


Map
an Rafael Bridge
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Richmond-San Rafael Bridge
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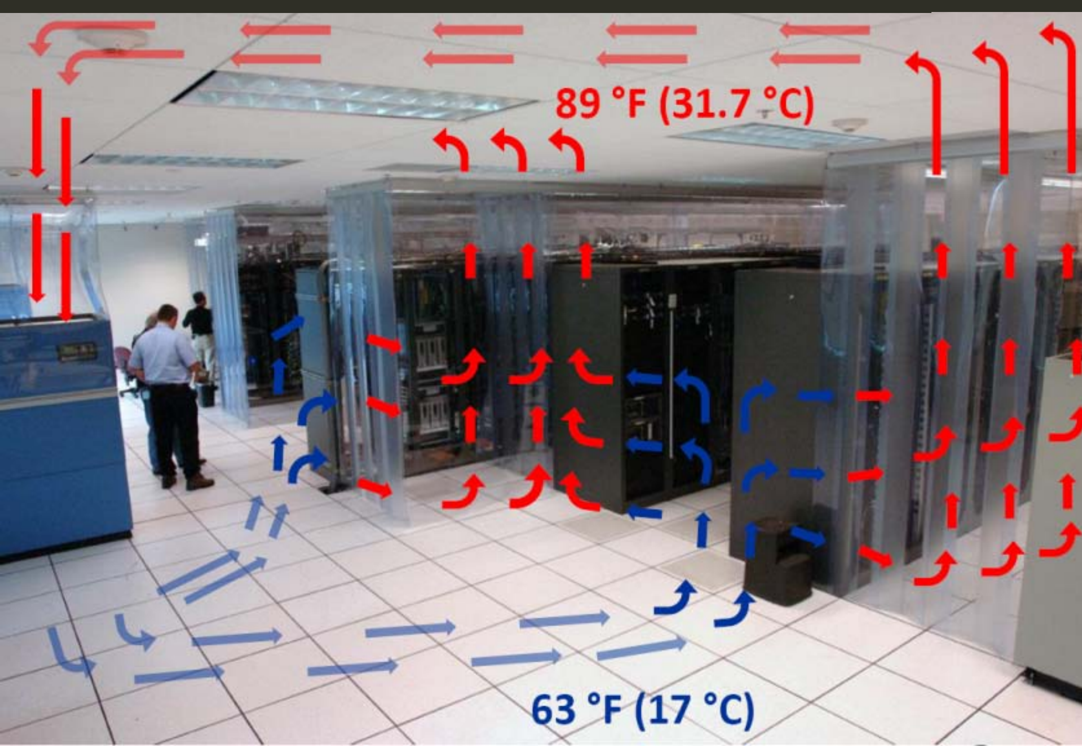
RNR MONEY CHANGER and Convenience Store
OPEN 24 HOURS
FOOD MART
MONEY CHANGER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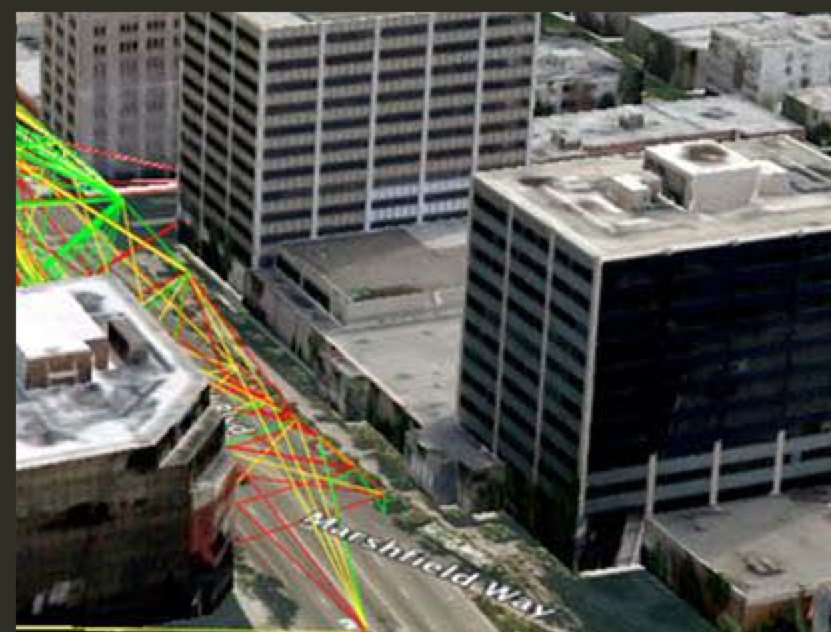

Marshfield Way

Vision 2030

- Integrated components will be approaching molecular limits and/or may cover complete walls
- Every object will have a wireless connection
- The "trillions of radios story" will be a reality
- The ensemble is the function
  - Function determined by availability of sensing, actuation, connectivity, computation, storage and energy
  - This brings virtualization to a new level

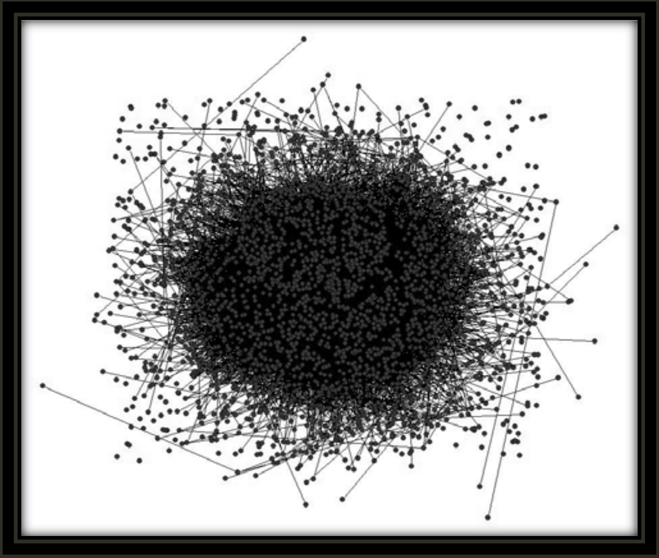
The Swarm at The Edge of the Cloud

TRILLIONS OF CONNECTED DEVICES

[J. Rabaey, ASPDAC'08]

The Swarm Perspective

Moore's Law Revisited:
Scaling is in number of connected devices,
no longer in number of transistors/chip



The functionality is in the swarm!
Resources can be dynamically provided based on availability

It's A Connected World

Time to Abandon the "Component"-Oriented Vision

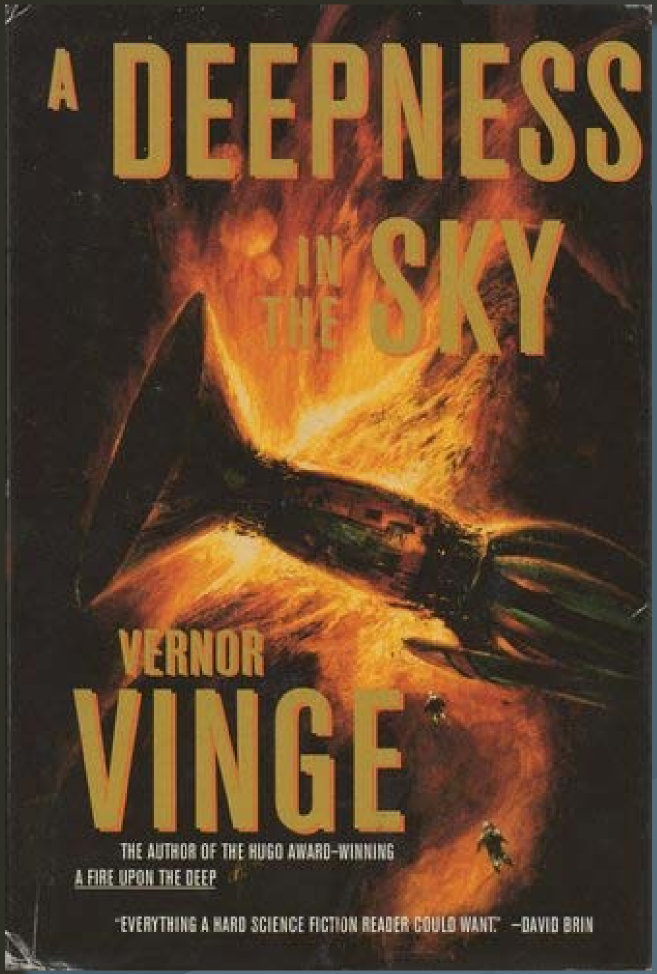
[J. Rabaey, MuSyC 2009]

Swarm Potentials

"Tiny devices, chirping their impulse codes at one another, using time of flight and distributed algorithms to accurately locate each participating device. Several thousands of them form the positioning grid … Together they were a form of low-level network, providing information on the orientation, positioning and the relative positioning… It is quite self-sufficient. Just pulse them with microwaves, maybe a dozen times a second …"

Pham Trinli, thousands of years from now

Vernor Vinge,
"A Deepness in the Sky," 1999



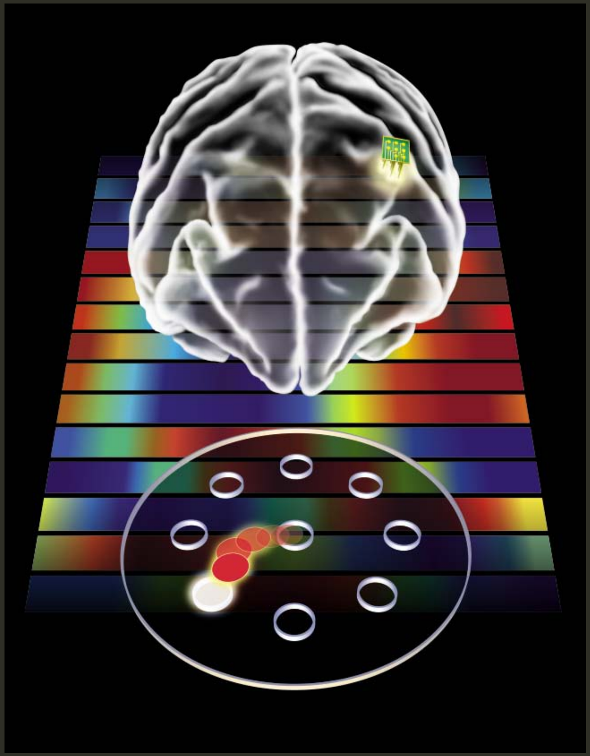
One Vision: CyberPhysical Systems

Linking the Cyber and Physical Words

[H. Gill, NSF 2008]

Another One: BioCyber (?) Systems

Linking the Cyber and Biological Worlds

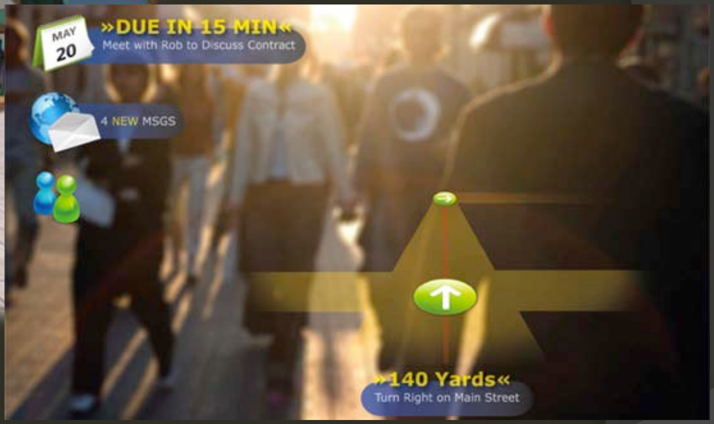


Examples: Brain-machine interfaces and body-area networks

What Bio-Cyber-Physical Systems Enable…

Vision 2030: The Age of the “UnPad”

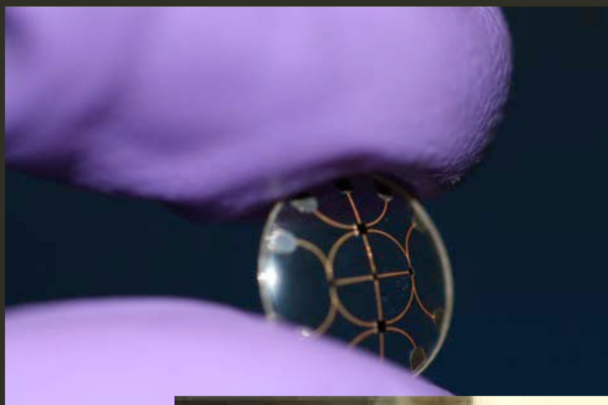
Computers and mobiles to completely disappear!

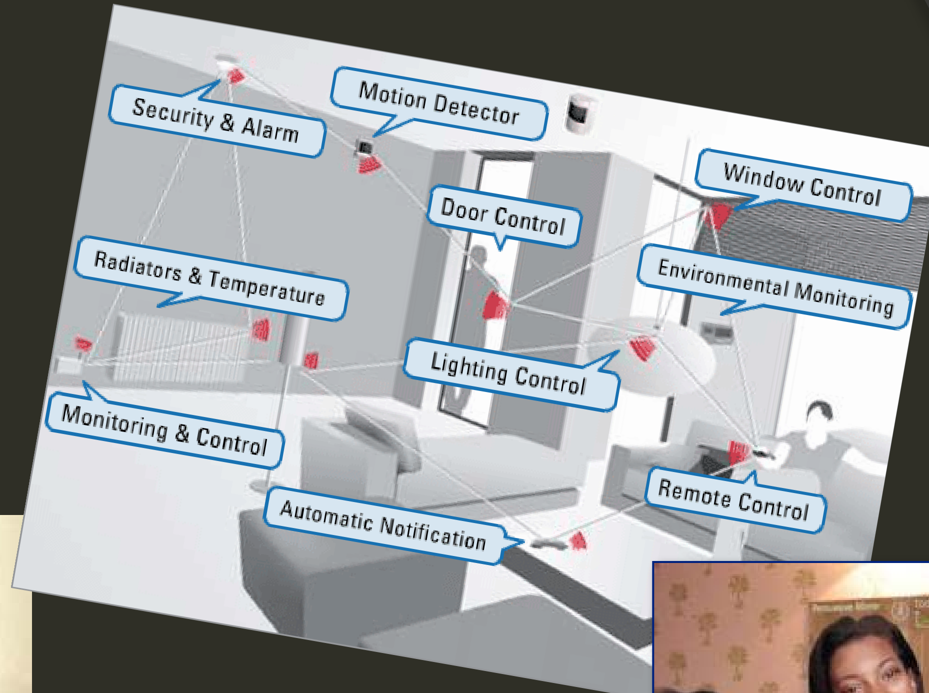


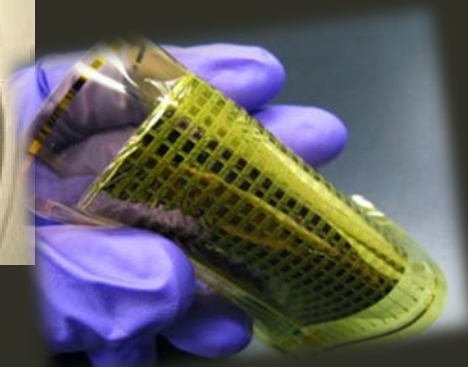
The Immersed Human

Always-available augmented real-life interaction between humans and cyberspace, enabled by enriched input (sensory) and output (actuation, stimulation) devices on (and in) the body and in the surrounding environment

The Disassembled Infopad







What it Takes …

- Seamless collaboration of huge numbers of distributed nodes – “the swarm”
- Huge communication challenges
  - Large numbers of multimedia data streams
  - Combined with critical sensing and control data
  - Varying degrees of availability, mobility, latency, reliability, security, and privacy
- Tremendous computational power
  - Generating true real-time enhanced reality
  - Mostly provided by the “cloud” – but latency issues dictate locality
- Distributed storage
- All within limited energy budgets

The Swarm "Playground"

Distributed Resources

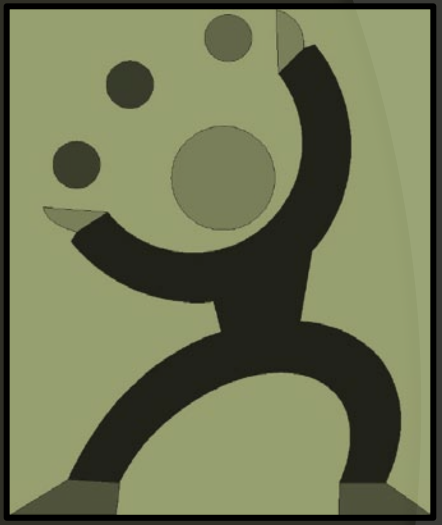
- Communication (Spectrum)
- Computation
- Sensing Actuation
- Storage
- Energy

The Swarm Operating System -
Dynamically trading off resources

The "Unpad" Services and Applications

Utility Maximization

"What matters in the end is the utility delivered to the user"



A continuously changing alignment
(environment, density, activity)

Making it Happen: “The Swarm Lab”

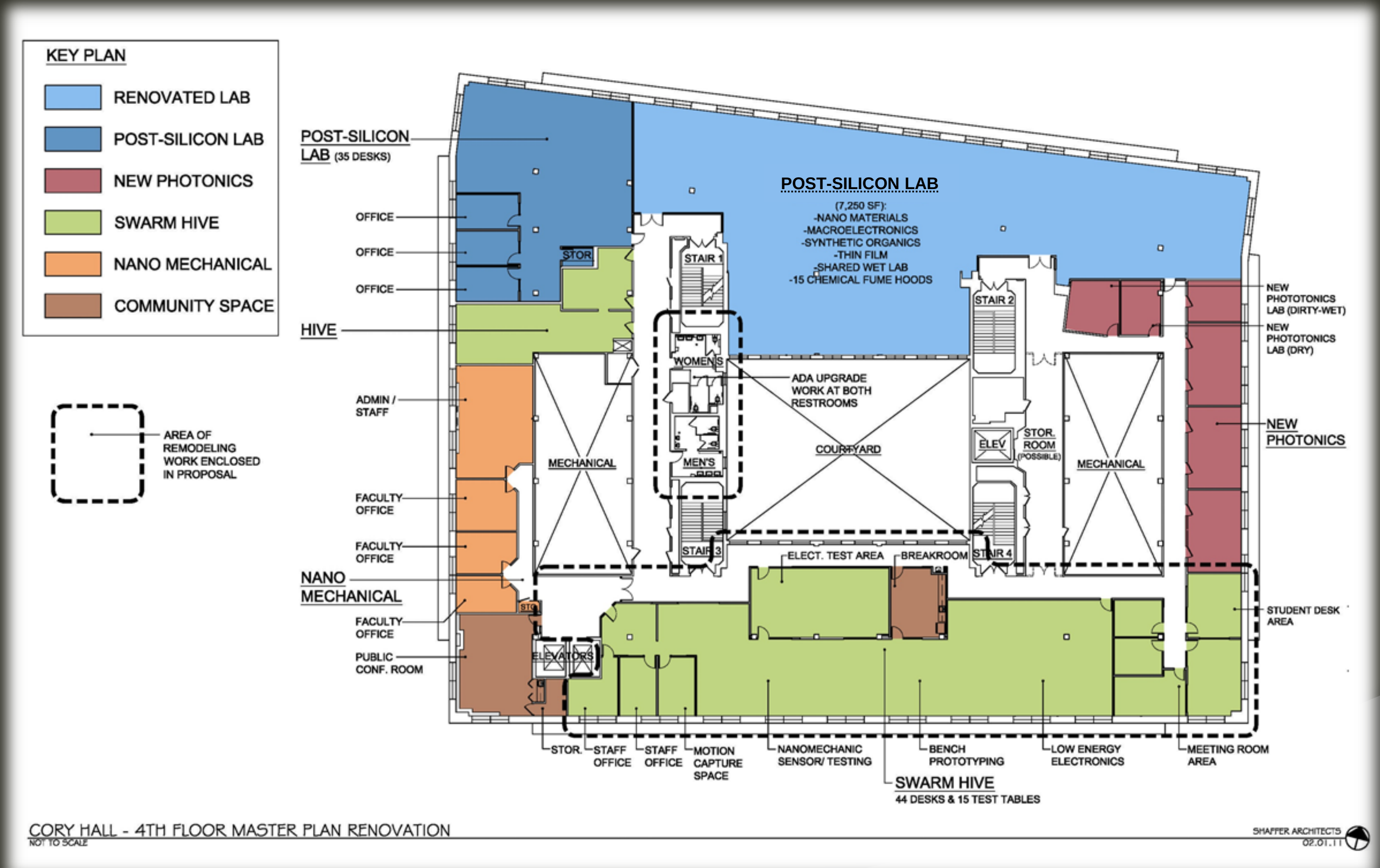
An experimental playground for the exploration and realization of innovative and disruptive swarm applications

Creation of the most advanced “swarm nodes”, exploring **post-Moore technologies and manufacturing strategies** combined with **ultra-low power implementation fabrics and architectures** for both computation, communication, storage, sensing and energy provision

Multi-disciplinary in nature, the lab combines researchers from diverse backgrounds covering the complete spectrum from application over integration to technology and materials.

Seeded by a major donation by Qualcomm, Inc

Opportunity:
A Whole Floor in Cory Hall

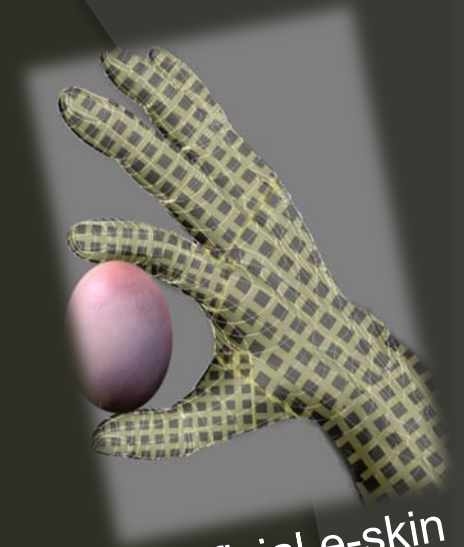


Enabled by the move of the microlab to Sutardja-Dai Hall (Marvell Lab)

The Post-Si Lab

Innovative Electronics Materials and Device Technologies for Future Integrated Systems

- Utilizing our strengths in novel electronic materials (e.g, III-V on Si and plastics, nanostructures, graphene, organics), and devices for exploring a broad range of alternative technologies to the traditional silicon scenario.
- Developing an entirely new processing platform for integrated electronics and sensors, and energy harvesting systems.

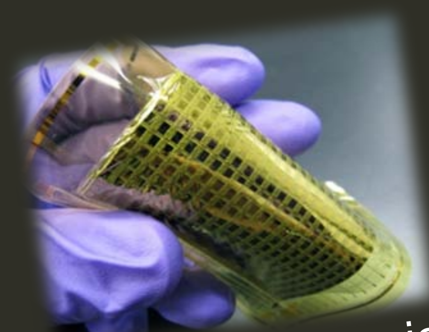


artificial e-skin

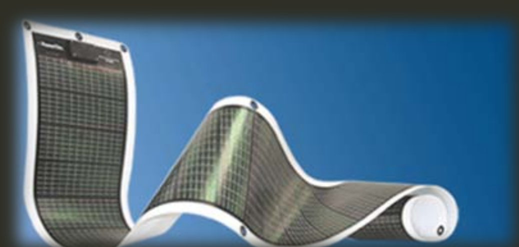
Roll-2-Roll Processing

Food freshness sensors

Paper-like displays



Flexible electronics



PV rolls

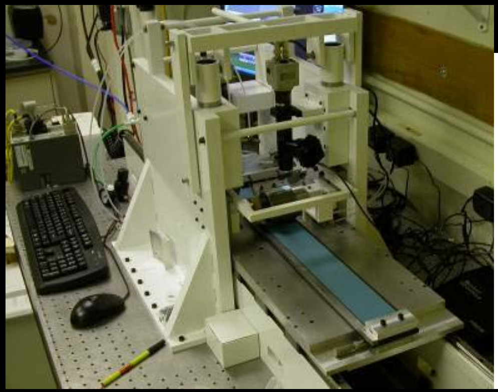
XoY Electronics: All-on-All

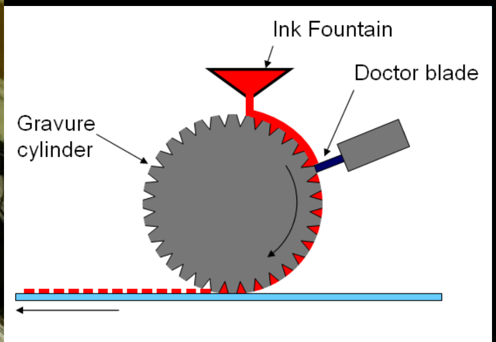
Interfacing EE and chemistry through materials innovation.

Bendable, Wearable, Paper-Like Electronics & Sensors

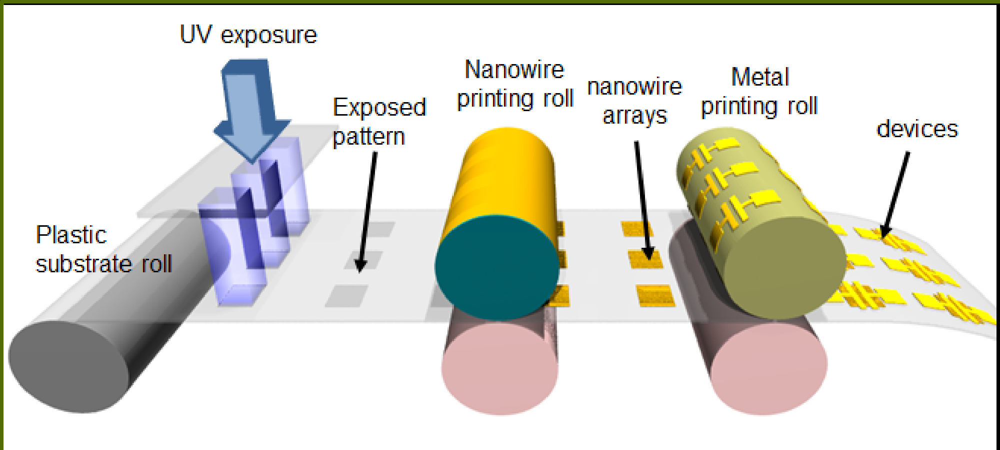
Materials, Devices, and Processing Technologies for Conformal Integrated Systems

Berkeley Approaches and Technologies:



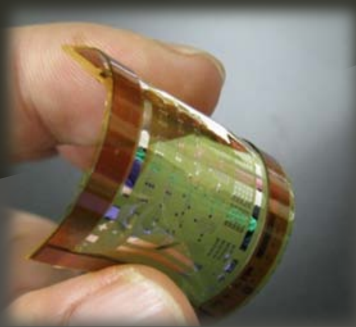


gravure/ink jet printing of semiconductors & conductors



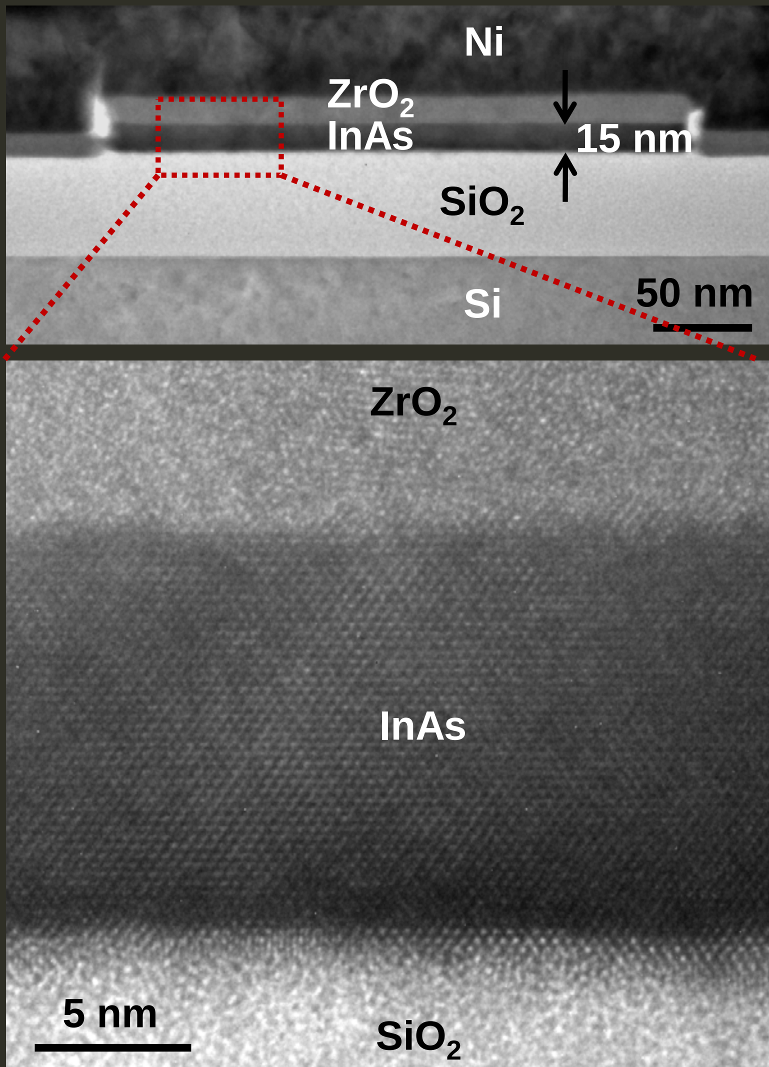
printing of nanoscale semiconductors

Printed FETs, Passives, and Energy Devices on Bendable, Flexible Substrates



XOI – Heterogeneous Integration of Compounds on Si

CMOS Extension and CMOS Plus



Example System:
Ultrathin body InAs-on-insulator MOSFETs

Need for Heterogeneous Integration

- ❑ Wide spectrum of materials with tunable electrical and optical properties
- ❑ High drift velocity – Low power (green) electronics
- ❑ Added functionality – e.g., integrated sensors, detectors, LEDs, lasers, …. on Si

Fabrication Features for XOI

- ❑ III-V integration on Si/SiO_2 substrates – Wafer Bonding / Epilayer Transfer
- ❑ Nanoscale doping of contacts – Monolayer Surface Doping
- ❑ High quality interfaces – Surface passivation

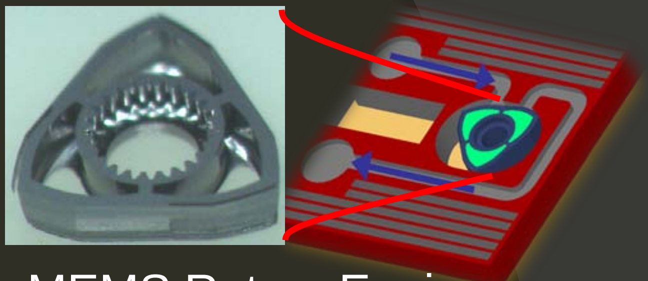
Device Advantages of XOI

- ❑ Enhanced electrostatics
- ❑ Reduced leakage currents
- ❑ Compatibility with CMOS/SOI
- ❑ Generic device architecture for different material systems

The Nano-Mechanical Lab

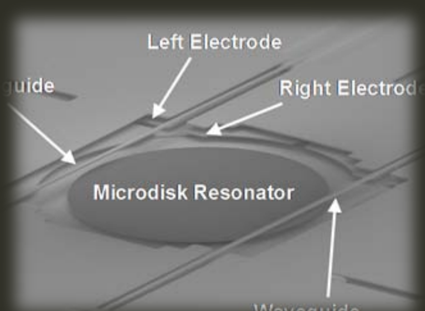
Harnessing the Benefits of Scaling in Domains Beyond the Electronic

- Explore the efficacy by which scaling and circuit/system level design using non-electronic (e.g., mechanical, thermal, fluidic, chemical) bases enable new capabilities and applications
- Realize needed swarm functions (e.g., sensing, communication, …) with high efficiency, low energy consumption, high specificity, and low false alarm rates

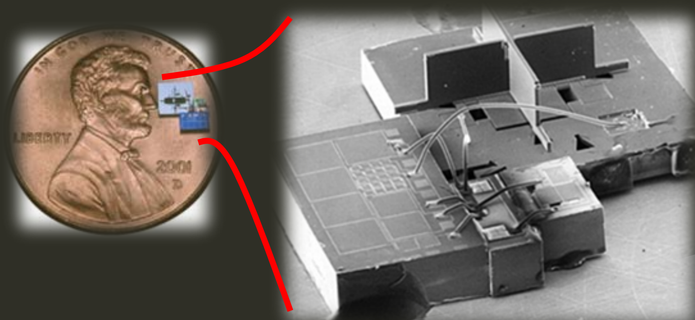


MEMS Rotary Engine Power Generator

NEMS RF Signal Processor



Micro Optical Sensor



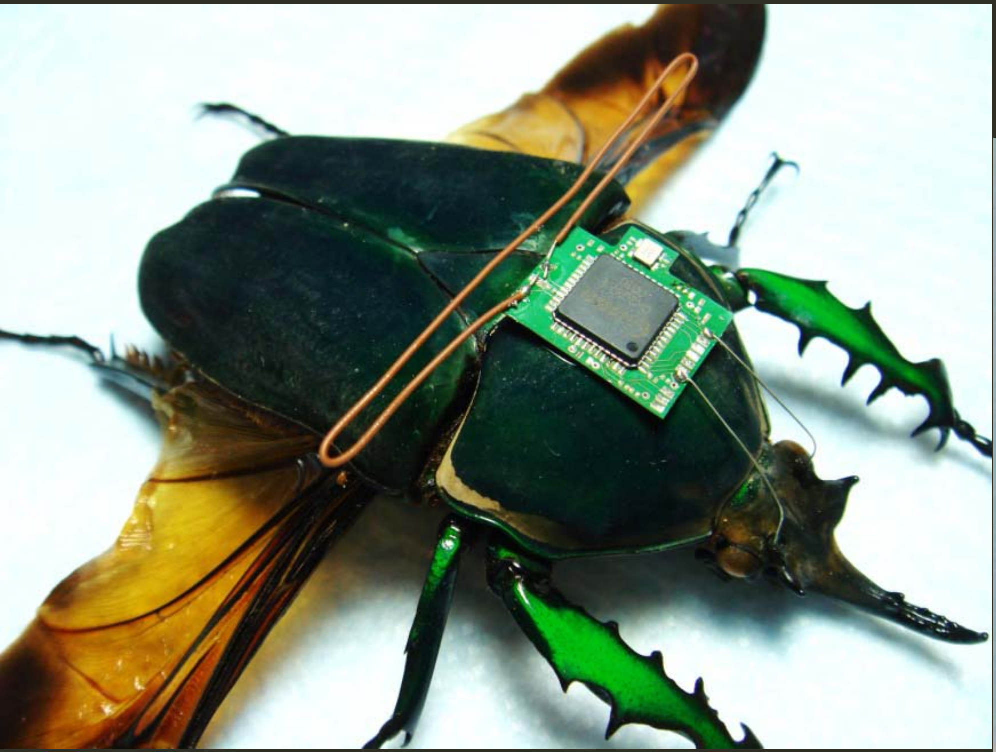
“Smart Dust” Micro/Nano Sensors

Cyborg Beetle

Low Power, mm-accurate Ultrasonic Rangefinding (Boser, Horsley)

- Low Power: ~100 microwatts
- Millimeter (3σ) accuracy over >0.7 meter range
- Tiny (1mm^3) volume

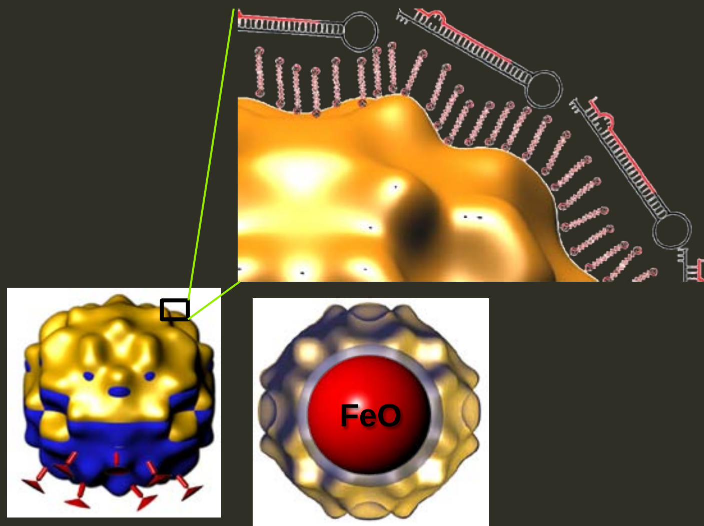
Micro-cyborgs



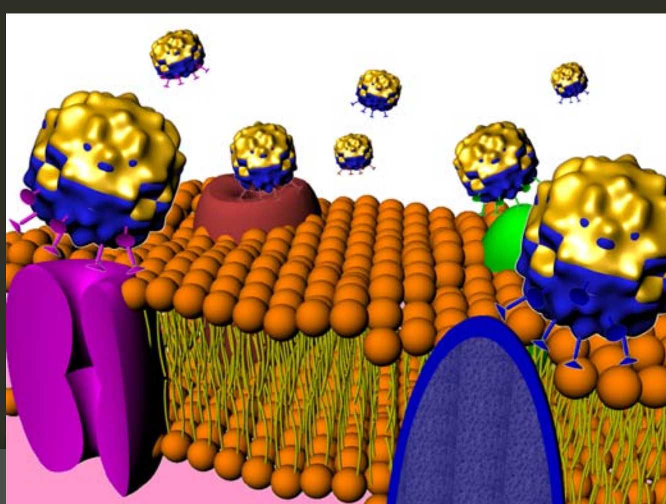
Michel Maharbiz

Nanosatellites

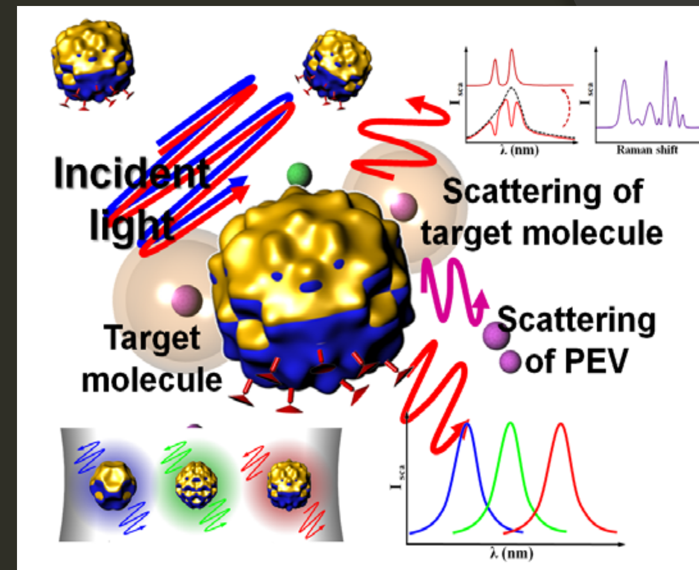
Luke Lee Group



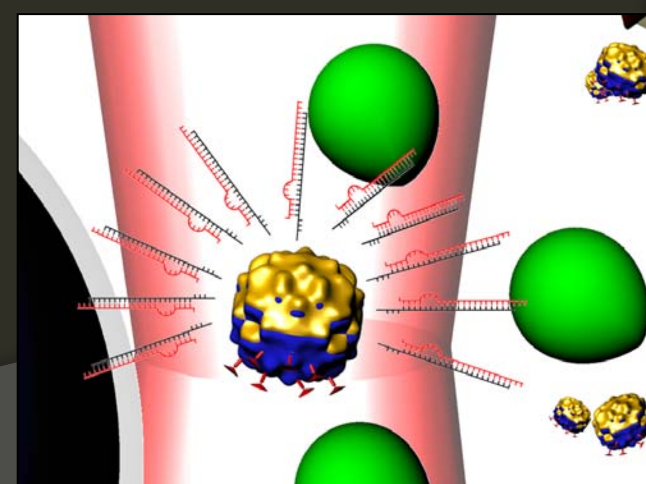
1. Targeting



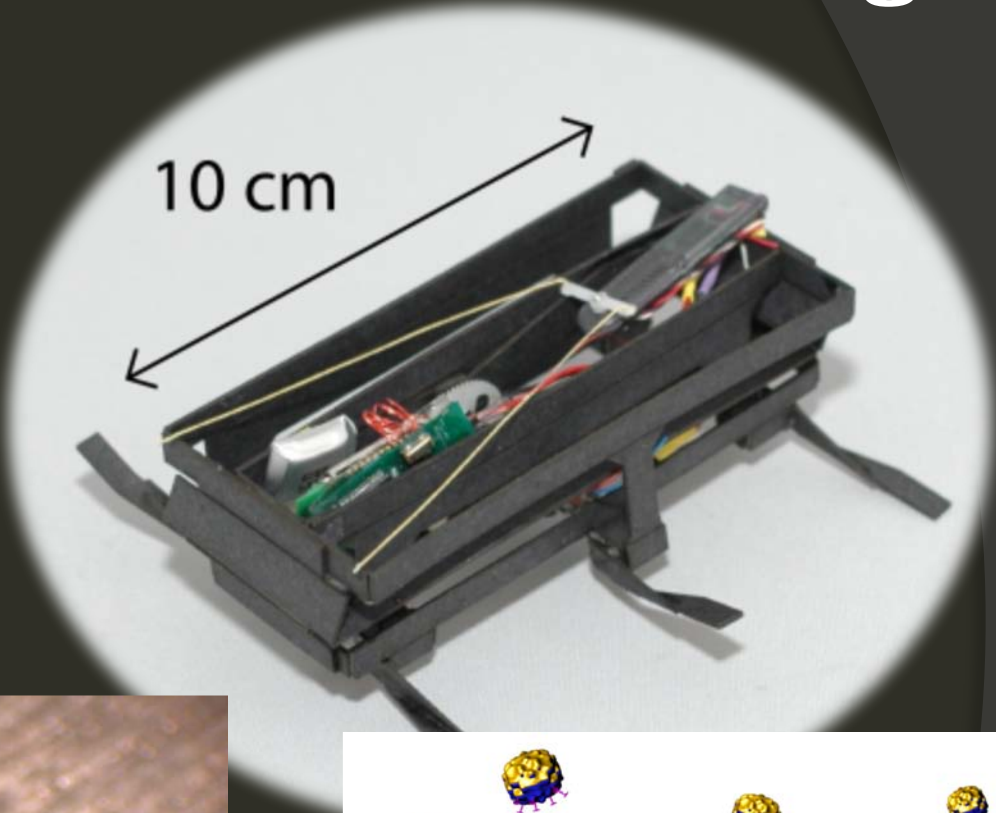
2. Imaging

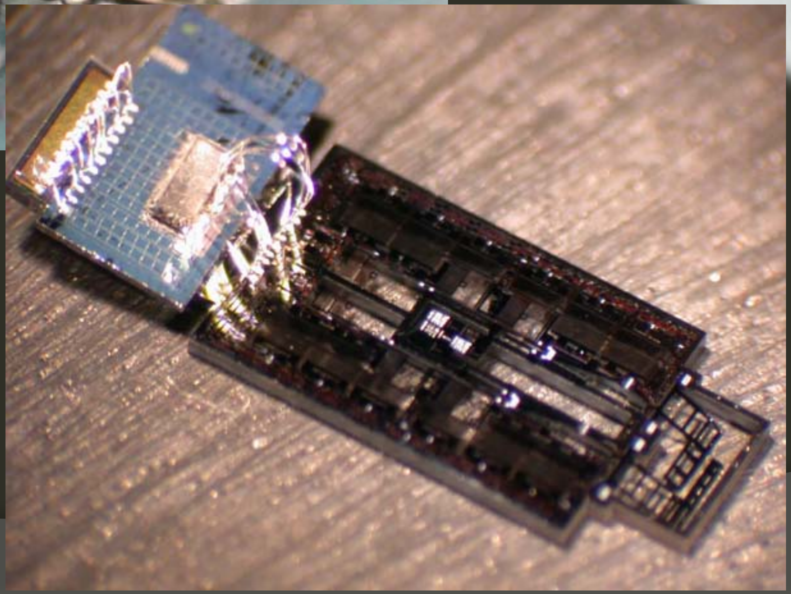


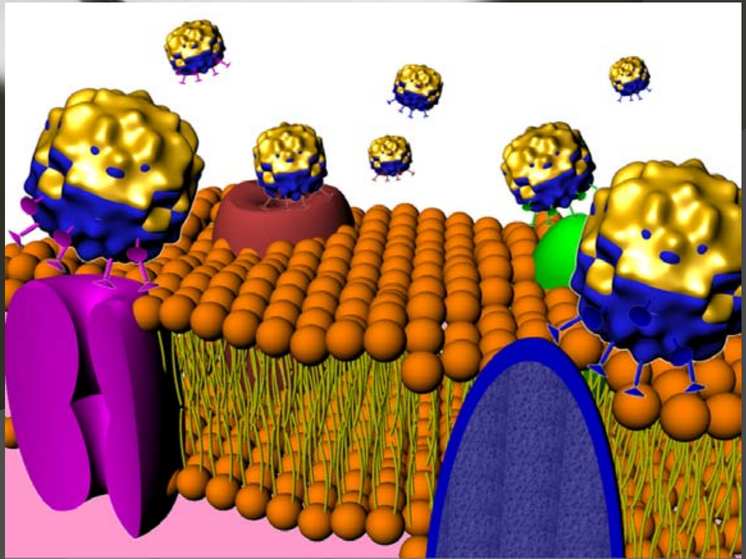
3. Gene delivery



A swarm of robots to do our bidding





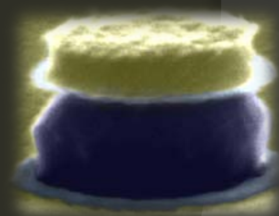


The New Photonics Lab

Integrating Photonics for Sensing, Communication and Power Generation

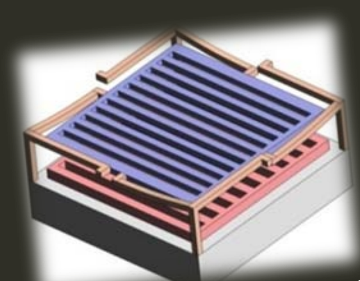
- Solar cells with unprecedented efficiency for energy generation/harvesting
- New Materials to create high quality thin films
- Nanoscale lasers and LEDs integrated on Si or plastics
- New display using nano-optomechanic devices
- Sub-wavelength optics for ultra-low power sensing and interconnects
- Wearable micro-LIDAR for instant 3D mapping

Solar Cells

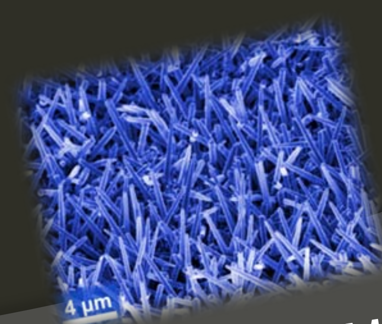


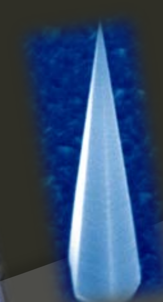
Nanolasers

Emissive Display



Sub-wavelength Optomechanics

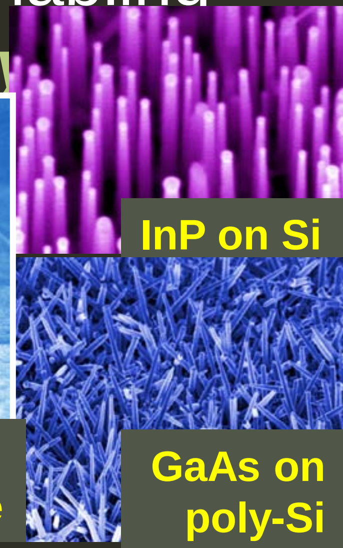




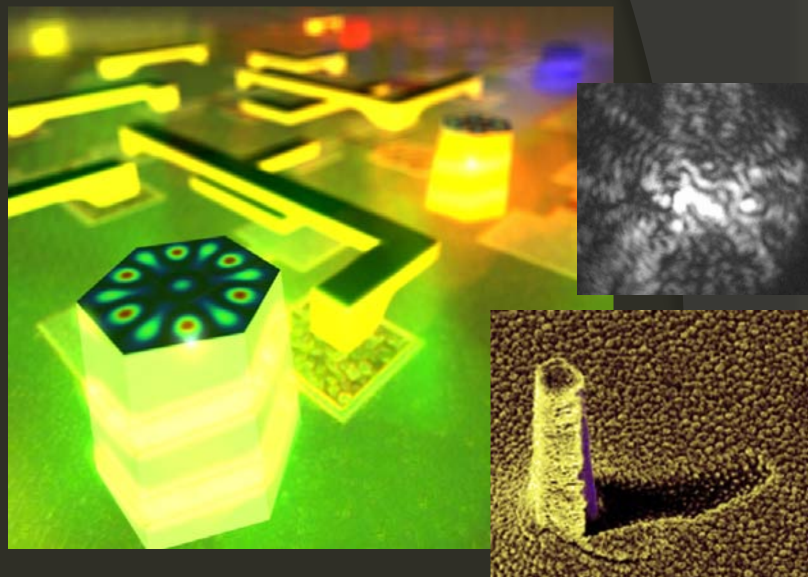
Nano Materials

Nano-Photonics for High Efficiency PV and LED

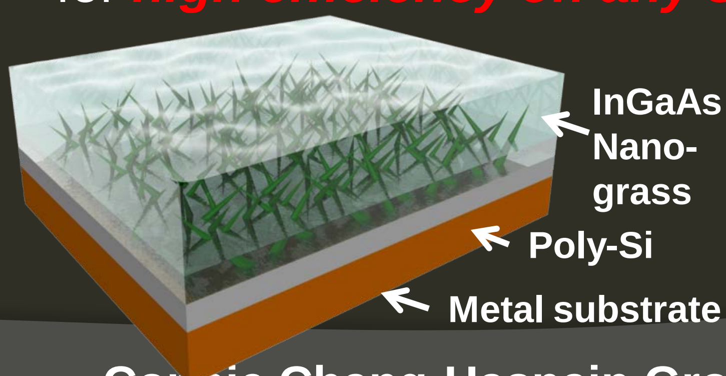
- **Nano-synthesis** enabling integration of *every*

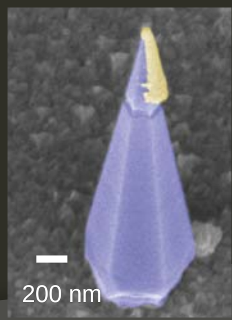


- **Nanolaser on MOSFET** enabling massive opto and electronics and integration

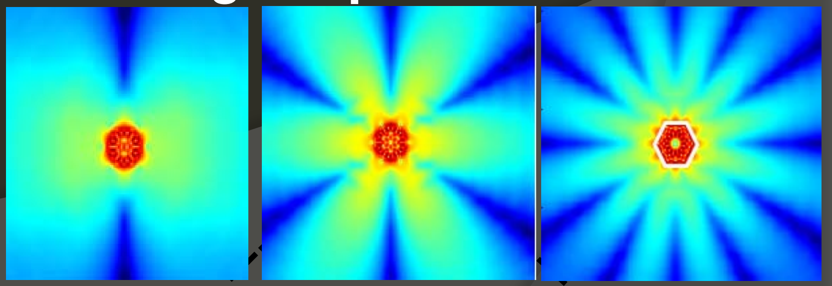


- **Nano-grass solar cells on poly-Si** with wide-angle ***light-trapping*** design for ***high efficiency on any substrate***





- **Modeling and Simulation of Sub-wavelength Optics**

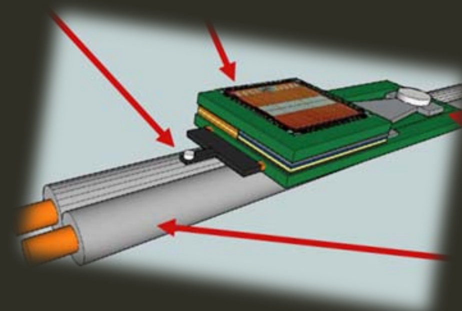


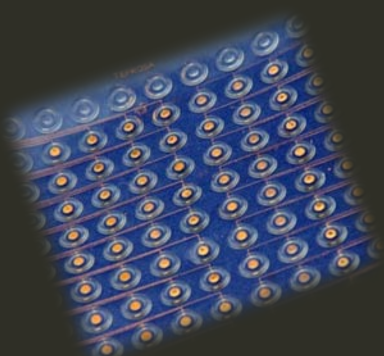
Connie Chang-Hasnain Group

The Swarm Hive

An Incubator for Swarm Applications and Platforms

- Integrating our strengths in advanced sensing, innovative post-silicon substrates and packaging, ultra-low power computing and communications, wireless links and networks, and distributed systems …
- To create entirely novel swarm solutions to applications such as the Unpad, health care, smart energy management, security, …





In a multi-disciplinary open lab-workspace setting

In close collaboration with other Berkeley Labs such as CITRIS, BWRC, BSAC, COINS, Marvell Lab, …

In Summary … The Laws of the Swarm

- In a connected world, functionality arises from connections of devices.
- Largest efficiency gain obtained by dynamically balancing available resources: computation, spectrum and energy.
- The dynamic nature of the environment, the needs and the resources dictate adaptive solutions.
- No one wins by being selfish. Cooperation and collaboration are a must.

Swarm in 2020

Almost Certainly:

- Printed *systems*
- XOI, XOY
- Efficient solar everywhere
- Photons in every chip
- No Watt unmonitored
- Instrumented cities
- Instrumented body

If We're Lucky:

- Sensornets extend our senses
- Micro robots extend our muscles
- The cloud extends our brains